

Modeling the Stratosphere: Chemistry, Dynamics, and Tropospheric Coupling

Larry Horowitz (GFDL)

**with Meiyun Lin (CICS), Pu Lin (CICS),
Shian-Jiann Lin (GFDL), and Lucas Harris (GFDL)**

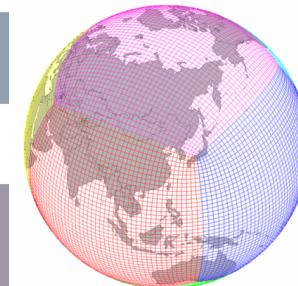
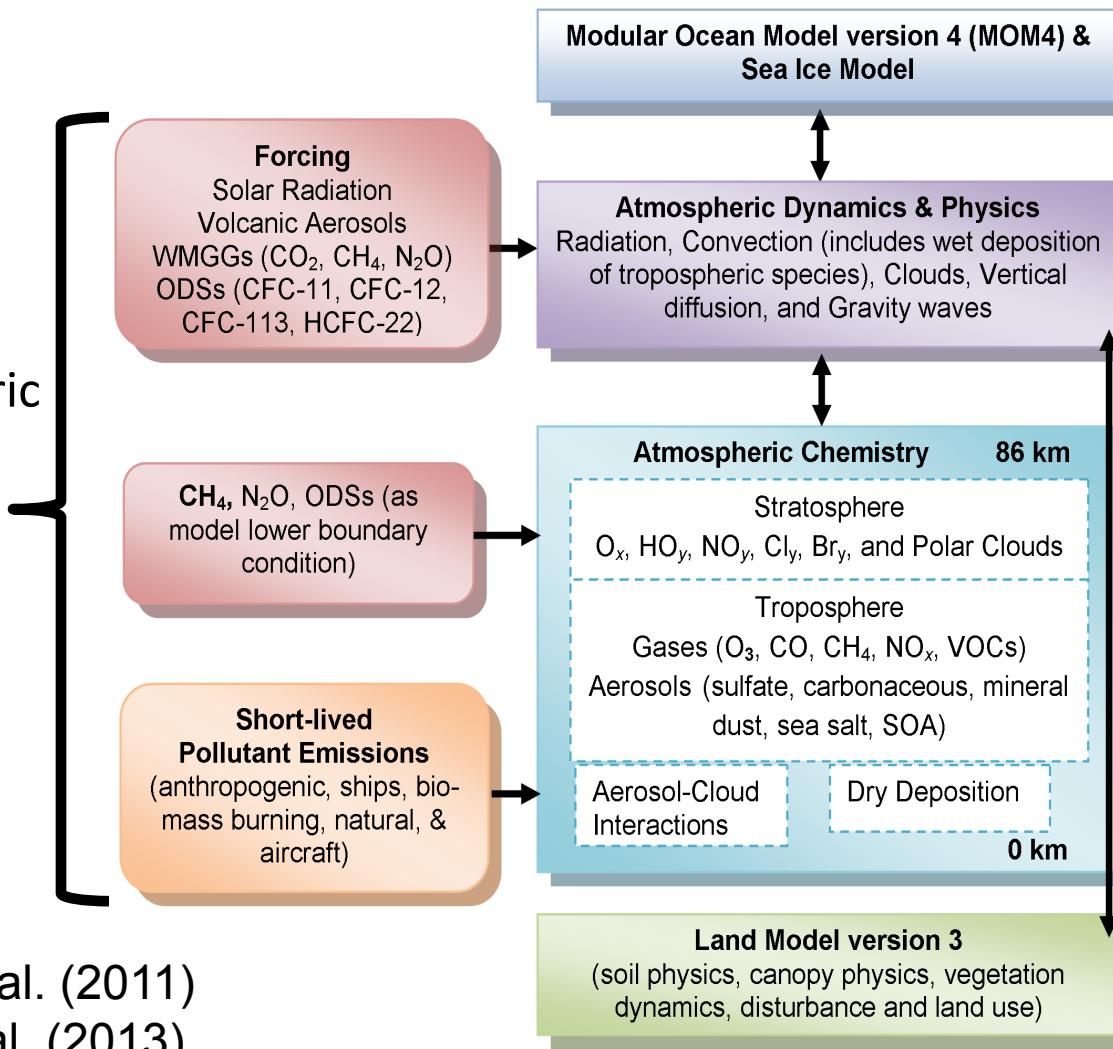


CM3 Coupled Climate Model

AM3

Atmospheric
Model

Donner et al. (2011)
Austin et al. (2013)
Naik et al. (2013)



Cubed
sphere
dynamical
core

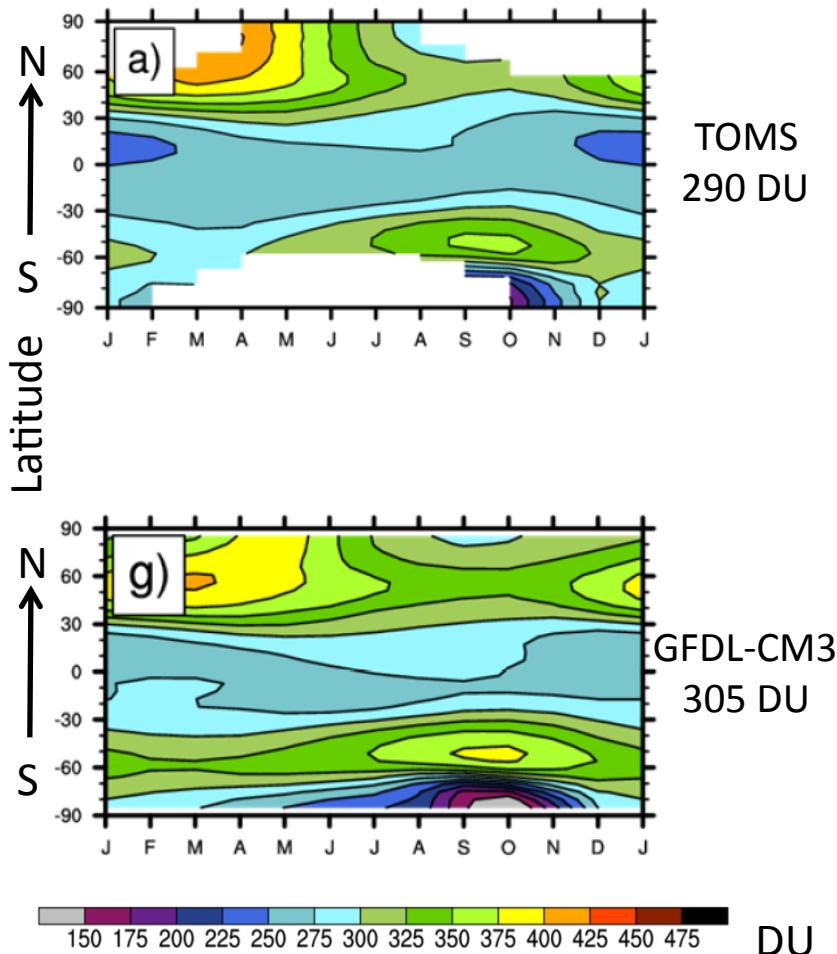
Putman and Lin (2007)

Designed to address:

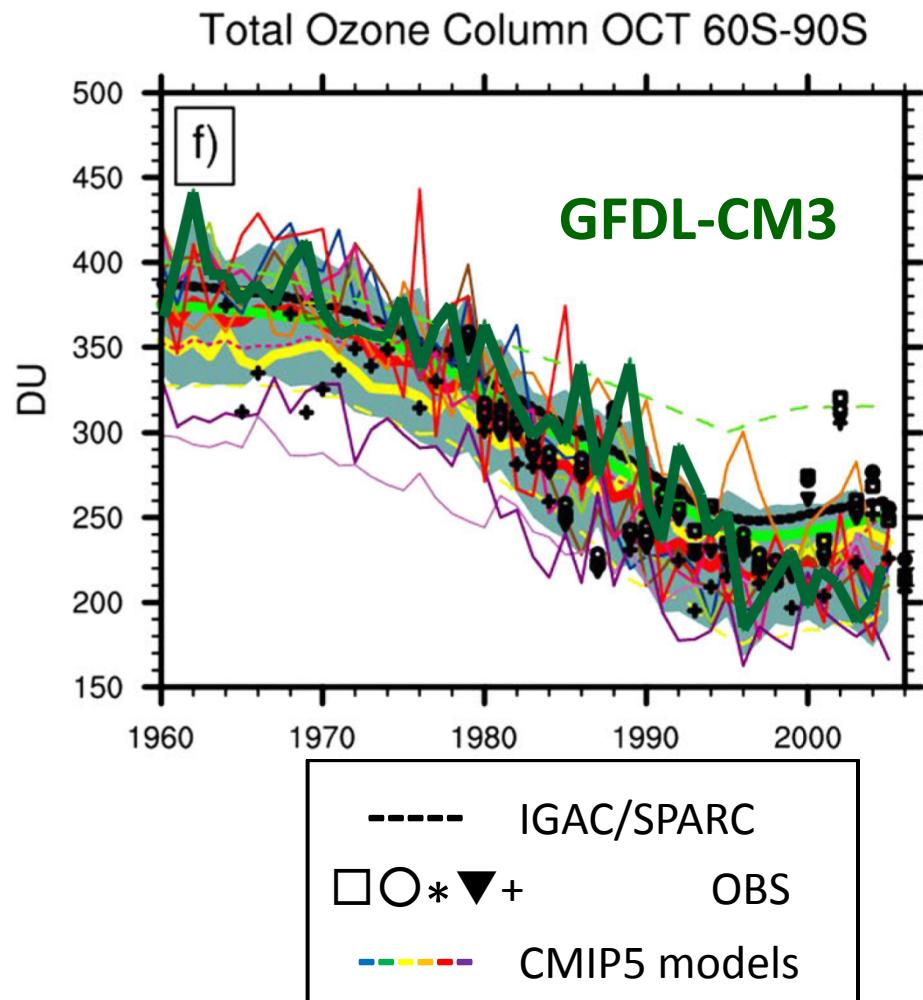
- Chemistry-climate feedbacks
- Stratosphere-troposphere chemical and dynamical coupling (high model top)
- Aerosol-cloud interactions

Stratospheric ozone distributions and trends are generally well simulated

Ozone Column

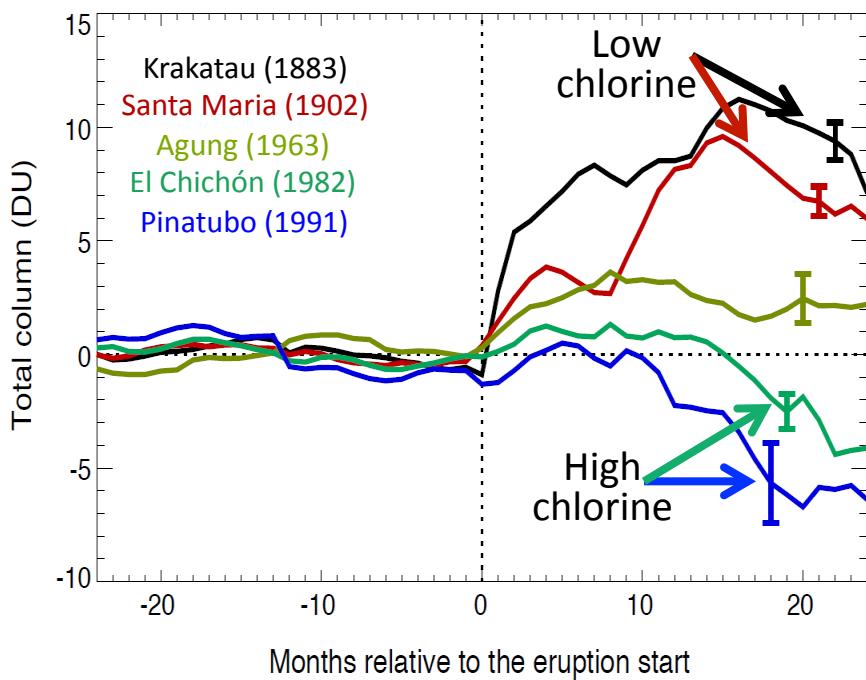


Development of Antarctic Ozone Hole

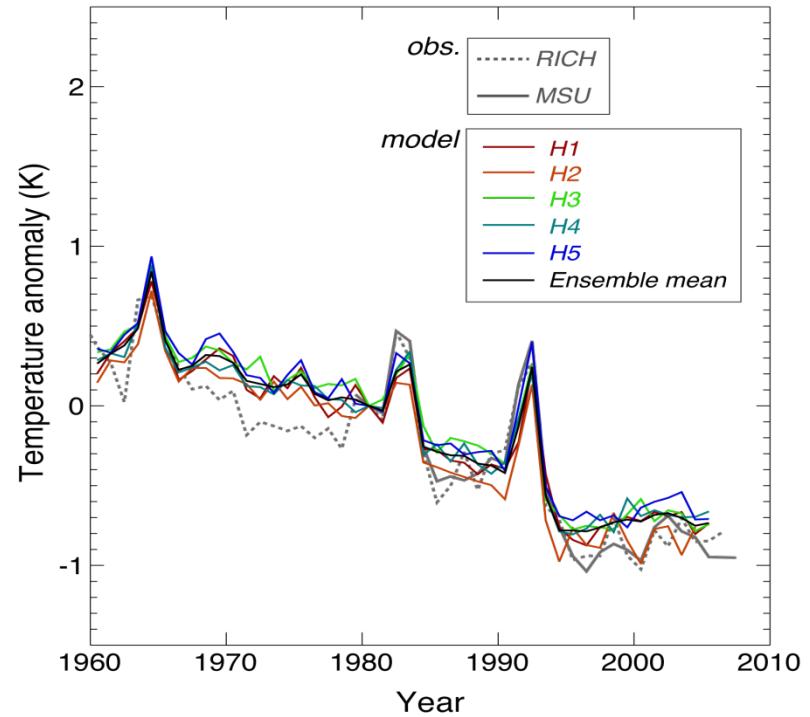


Stratospheric ozone and temperature respond strongly to volcanic eruptions

Ozone Column



Temperature

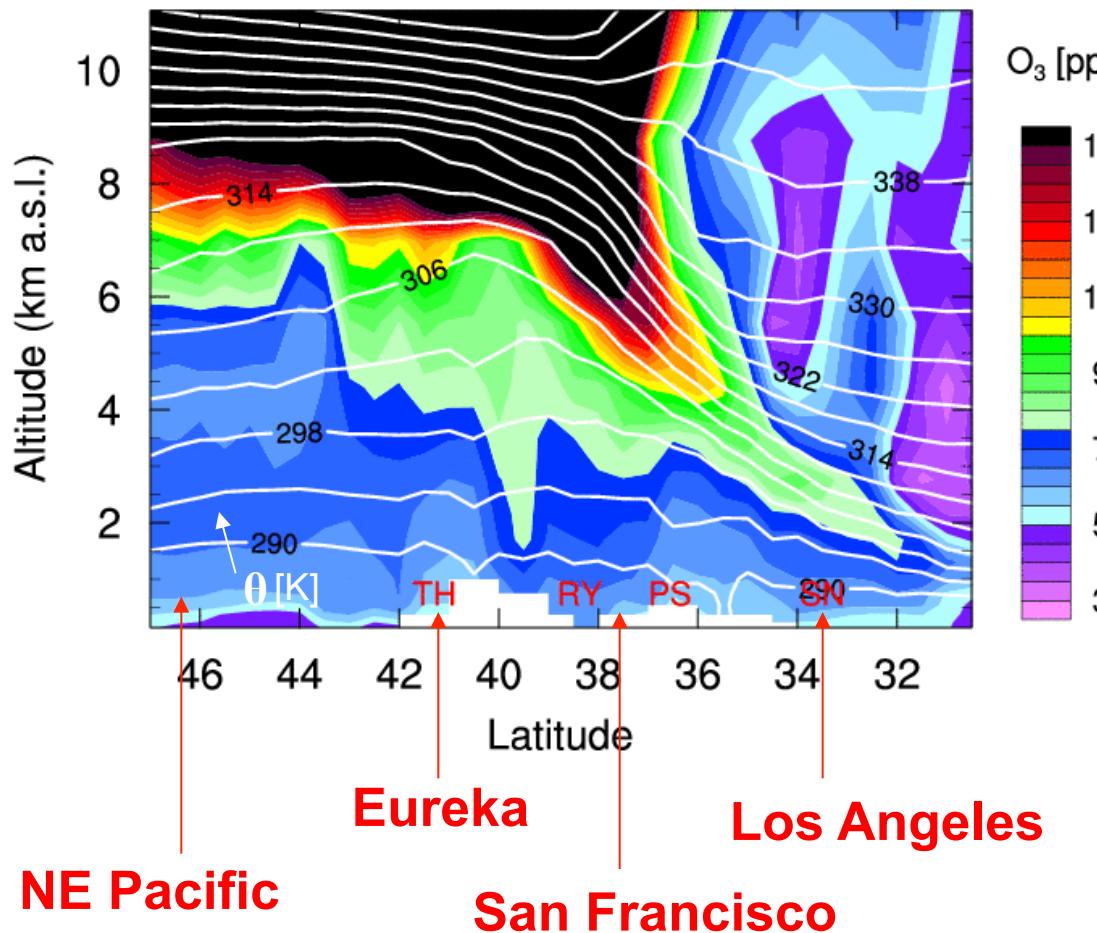


Sign of ozone response to volcanic aerosols depends on atmospheric chlorine loading

Post-volcanic warming and long-term cooling in stratosphere are well simulated by CM3

Deep stratospheric ozone intrusion

AM3 simulation of deep stratospheric O₃ intrusion over California 20100528T00:00:00



AM3 simulation using:

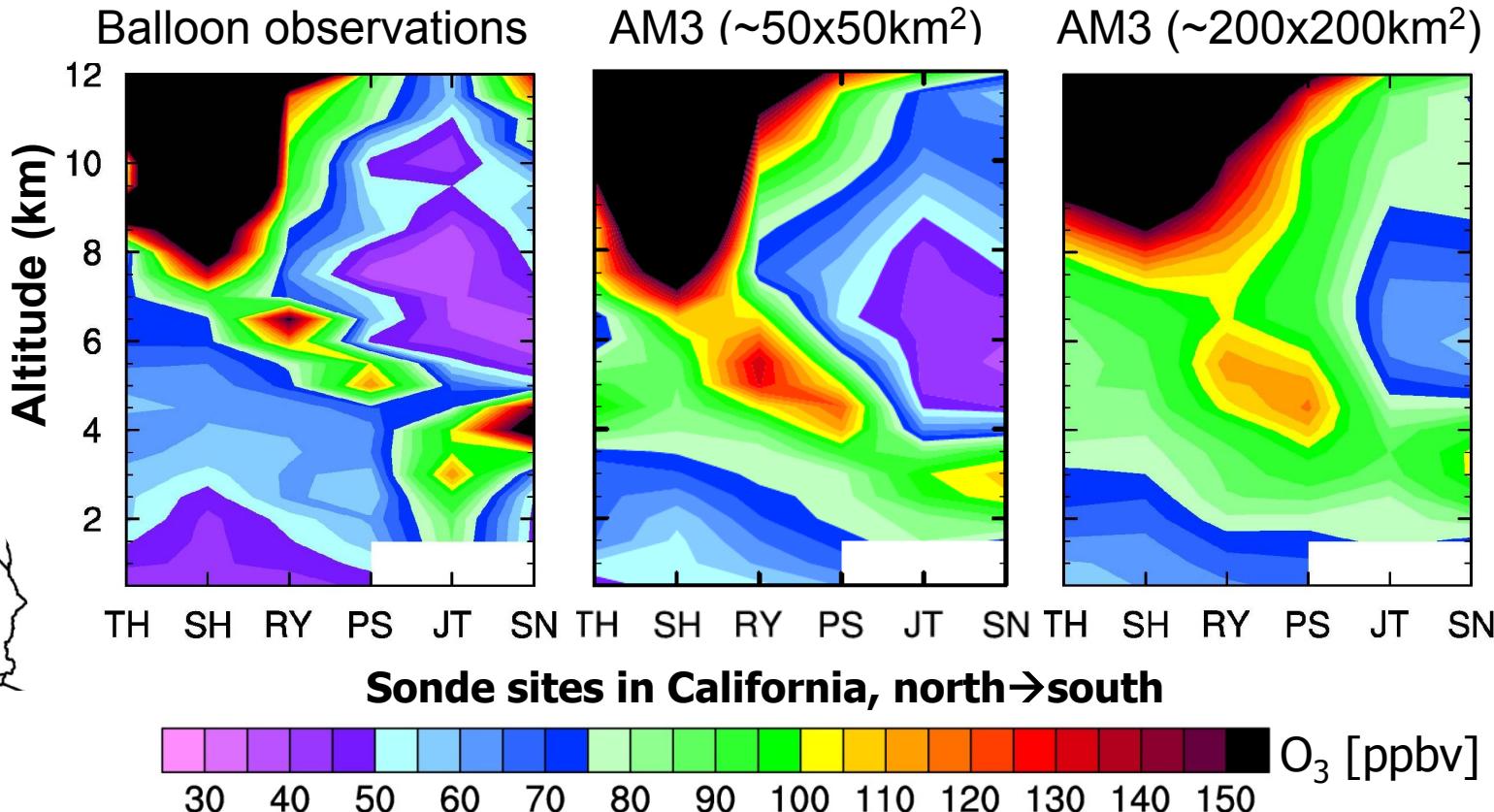
- C180 horizontal resolution (~50x50 km²)
- Full stratospheric and tropospheric chemistry
- Winds nudged to GFS analysis

Isentropic transport of stratospheric ozone to lower troposphere during event sampled by NOAA CalNex 2010

Deep stratospheric ozone intrusions captured by AM3

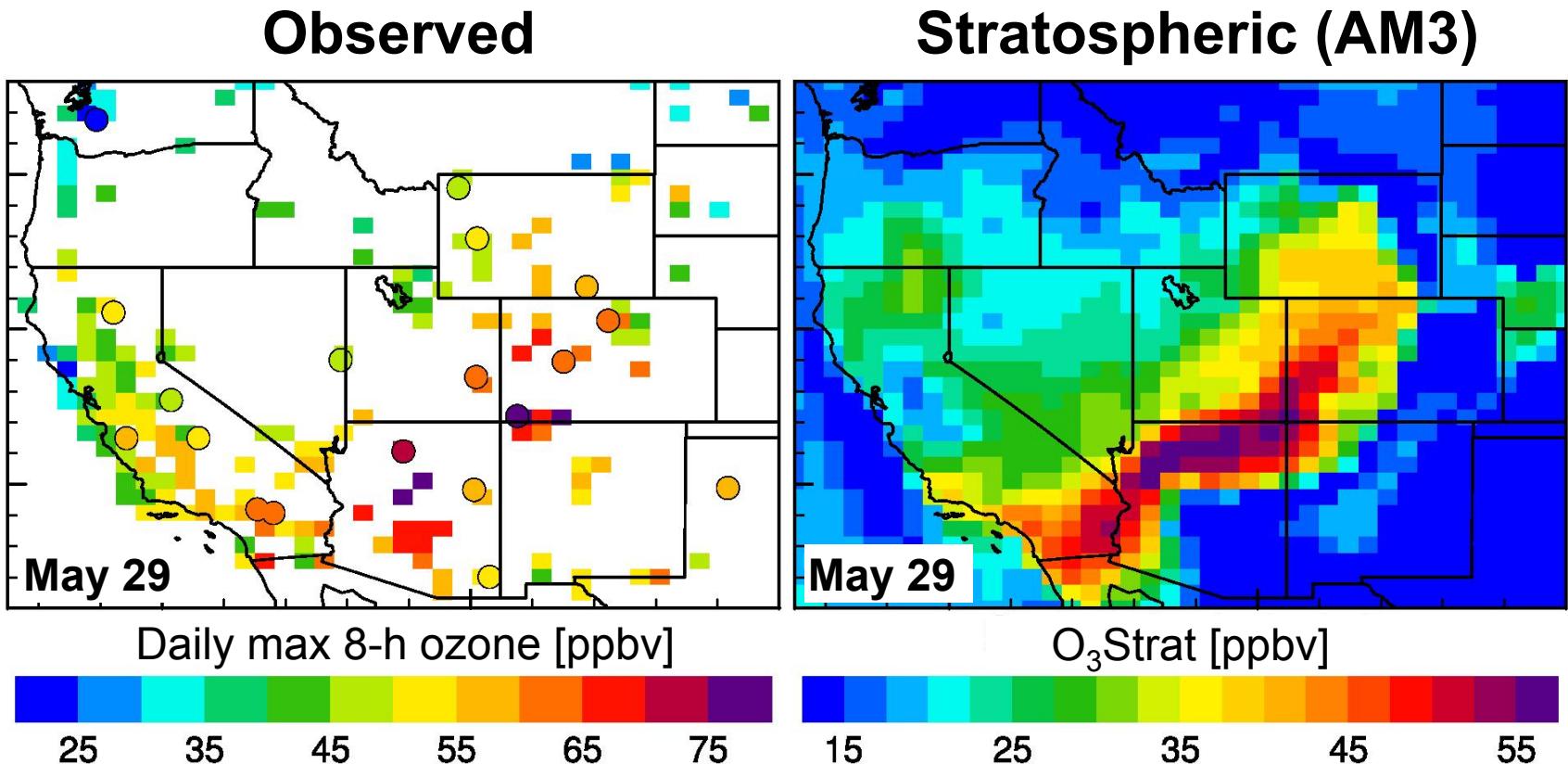
NOAA CalNex 2010 field campaign:
AM3 compared with ozonesonde observations

Case Study: May 28, 2010



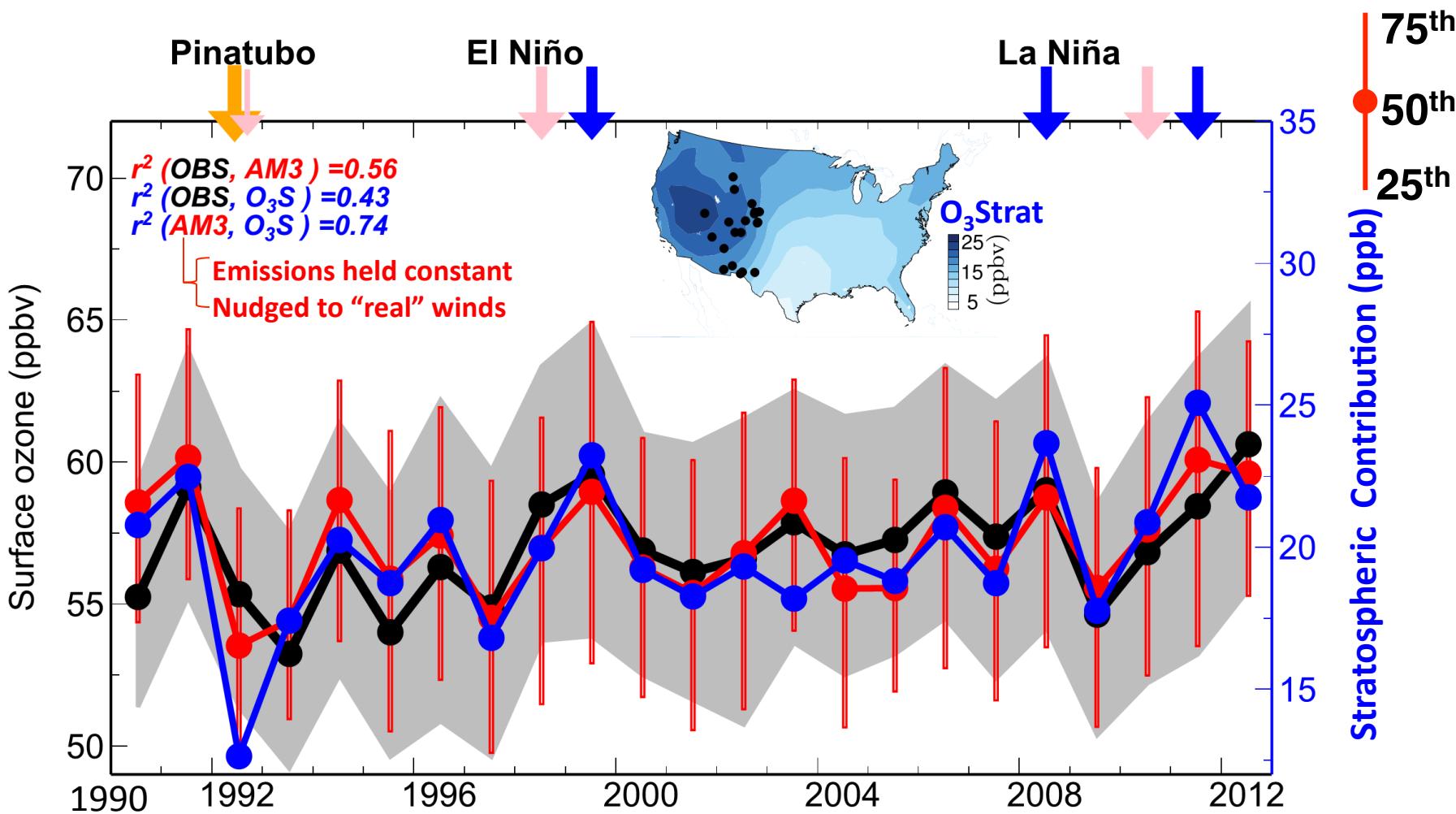
Stratospheric ozone penetrates to lower troposphere over southern California

Stratospheric O₃ impacts surface air quality

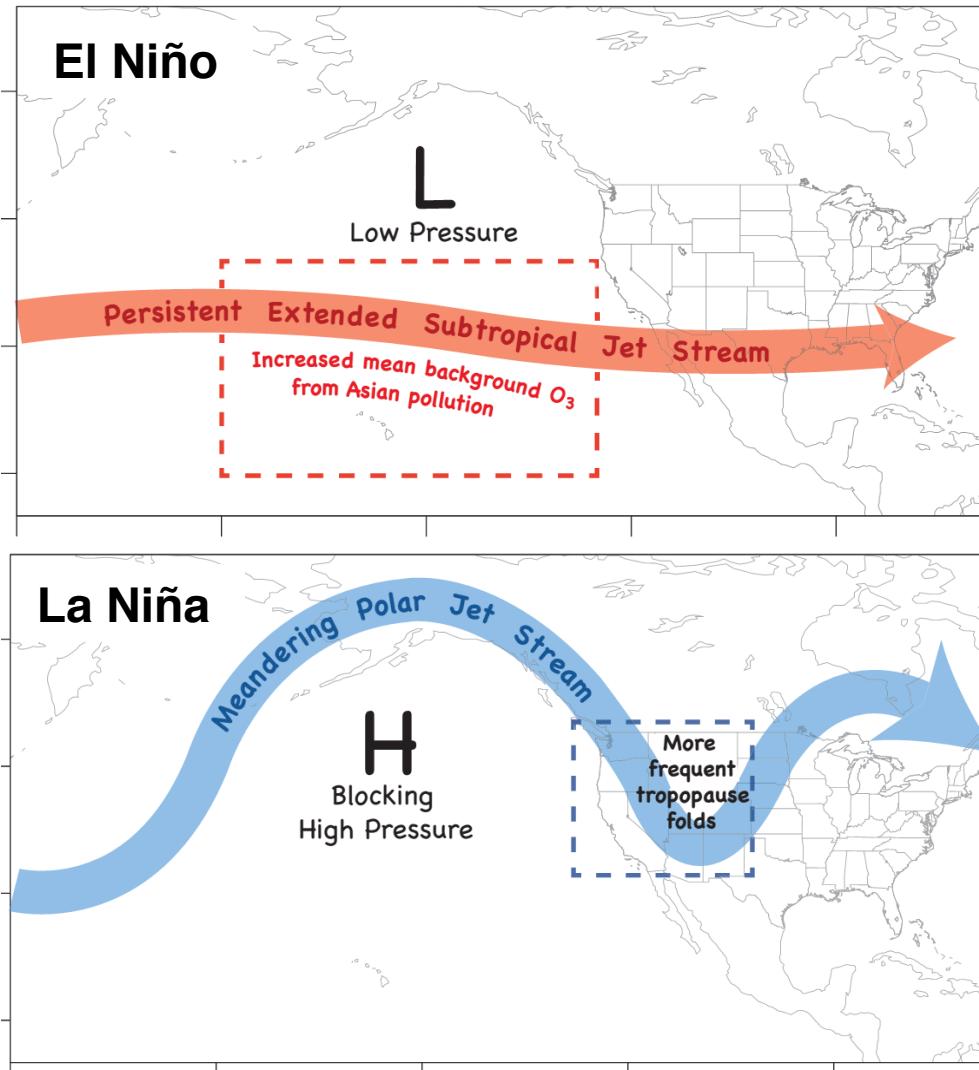


Stratospheric sources contribute episodically to high-ozone events above the health-based threshold

Stratospheric influence on interannual variability of surface O₃ over Western U.S. during April-May

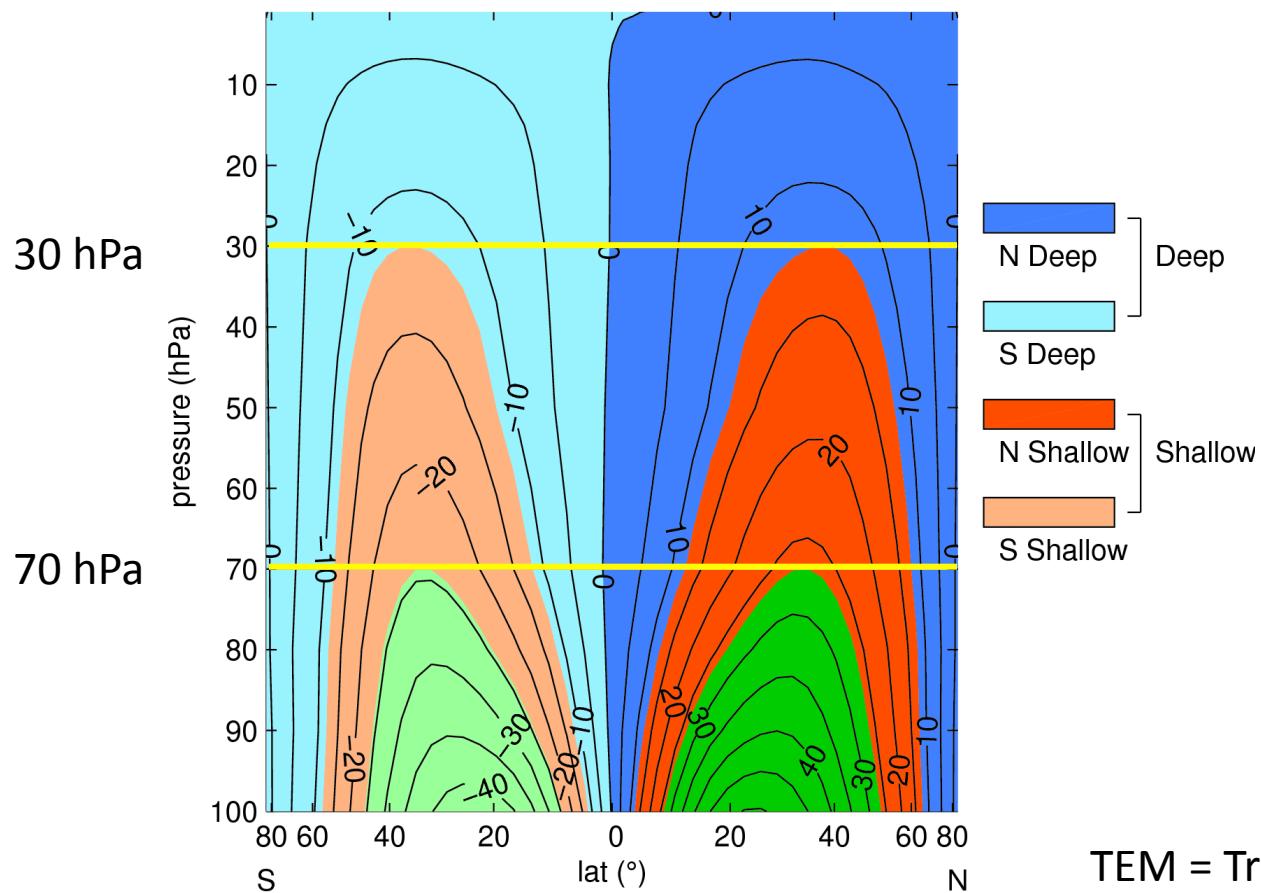


Wave-like jet stream under La Niña conditions ⇒ Deep tropopause folds and injection of stratospheric O₃



Diagnosing the Brewer-Dobson Circulation (BDC)

Annual Mean TEM Stream Function



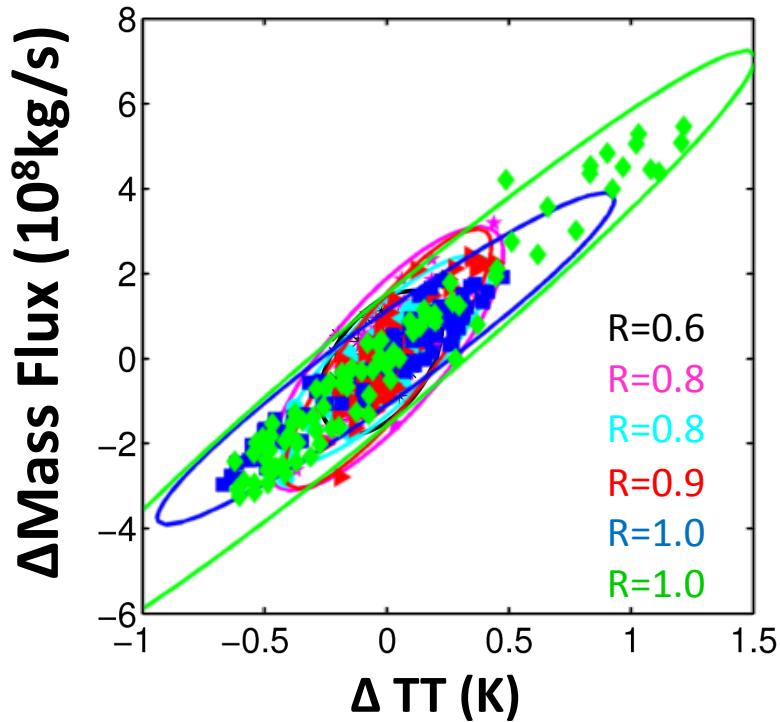
Climatological Strength (10^9 kg/s)

ERA-i	GFDL CM3
1.73	1.28
1.54	1.35
1.86	1.83
1.44	1.44

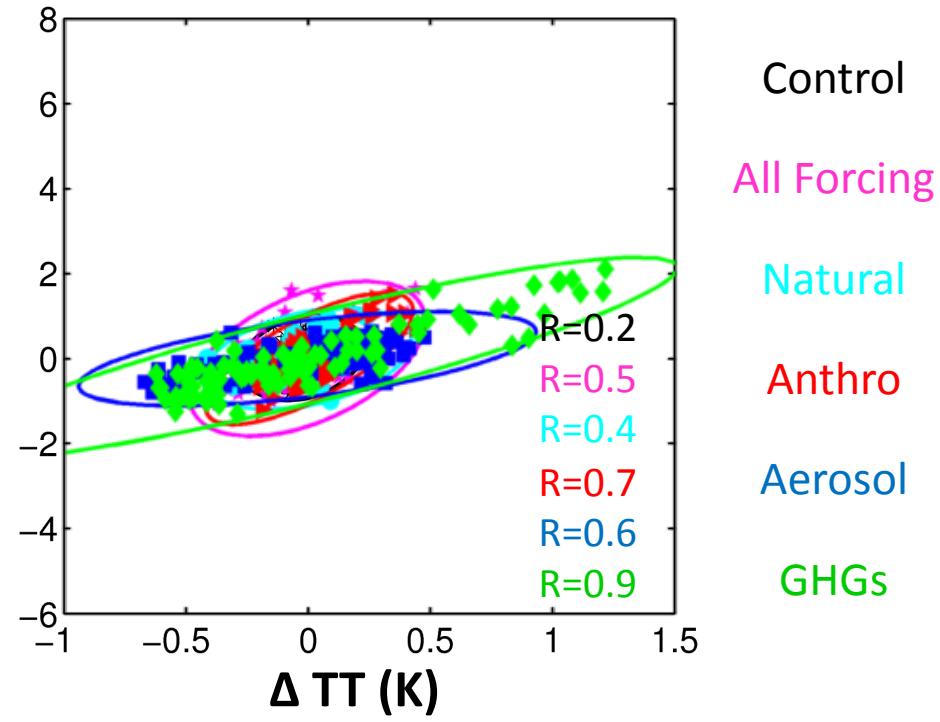
TEM = Transformed Eulerian Mean

BDC versus tropical surface T: decadal to multi-decadal variations

Shallow Branch

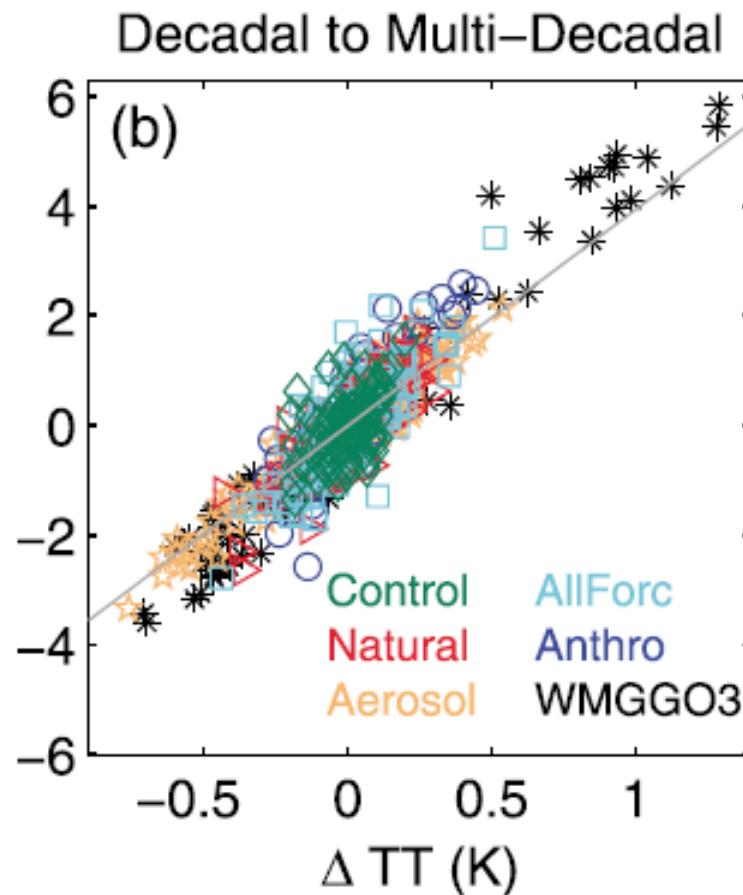
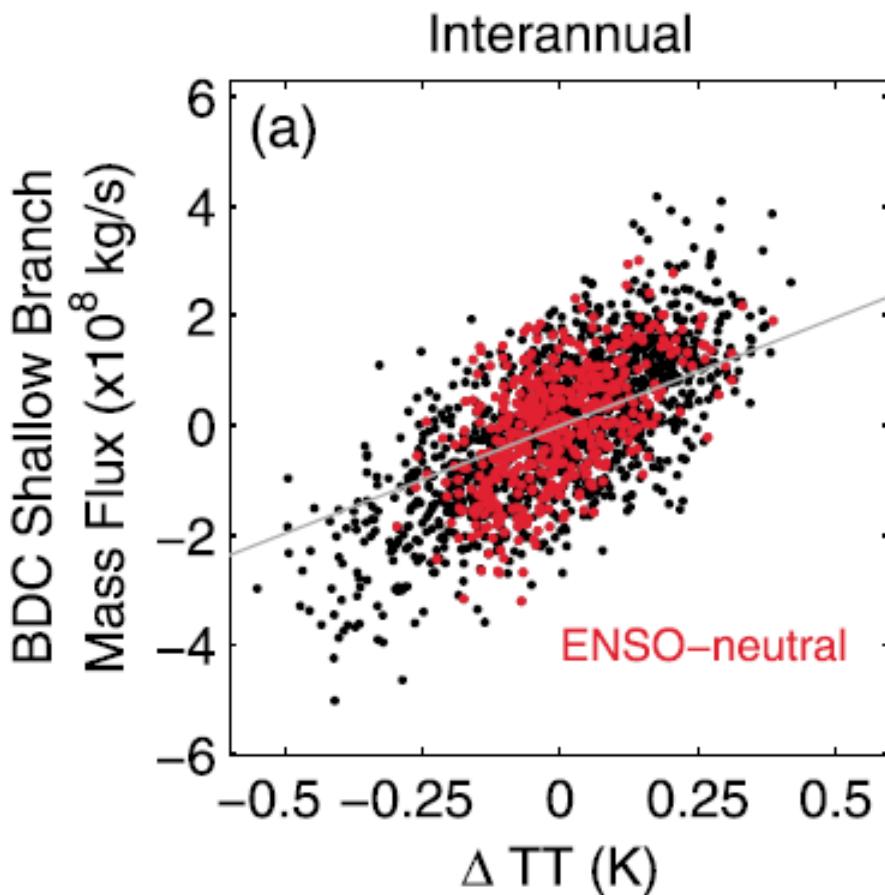


Deep Branch



**Shallow BDC well correlated with tropical surface temperatures,
for internal (unforced) variability and various external forcings**

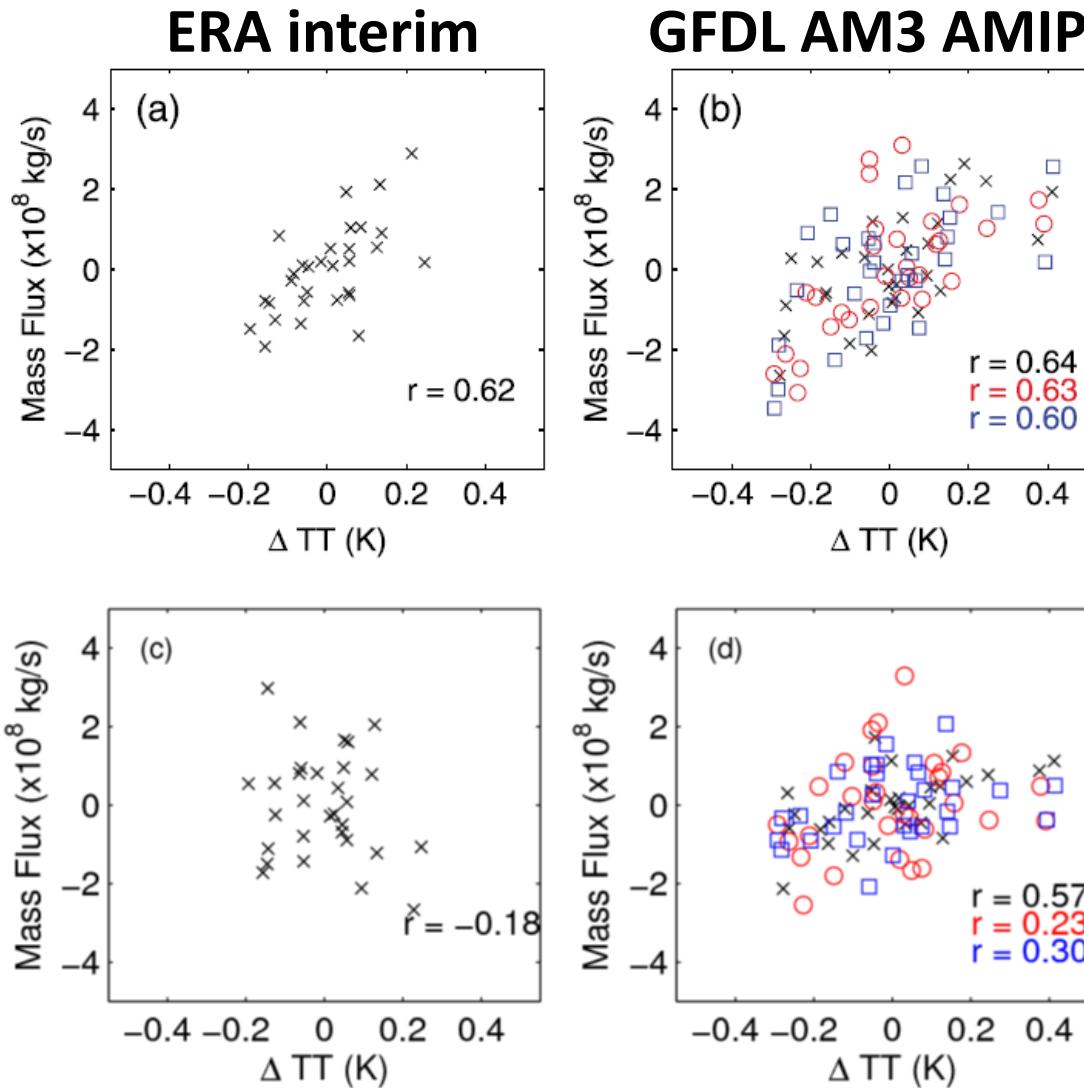
Shallow BDC versus tropical surface T: similar correlations across timescales and forcings



BDC versus tropical surface T: internannual variability in recent decades

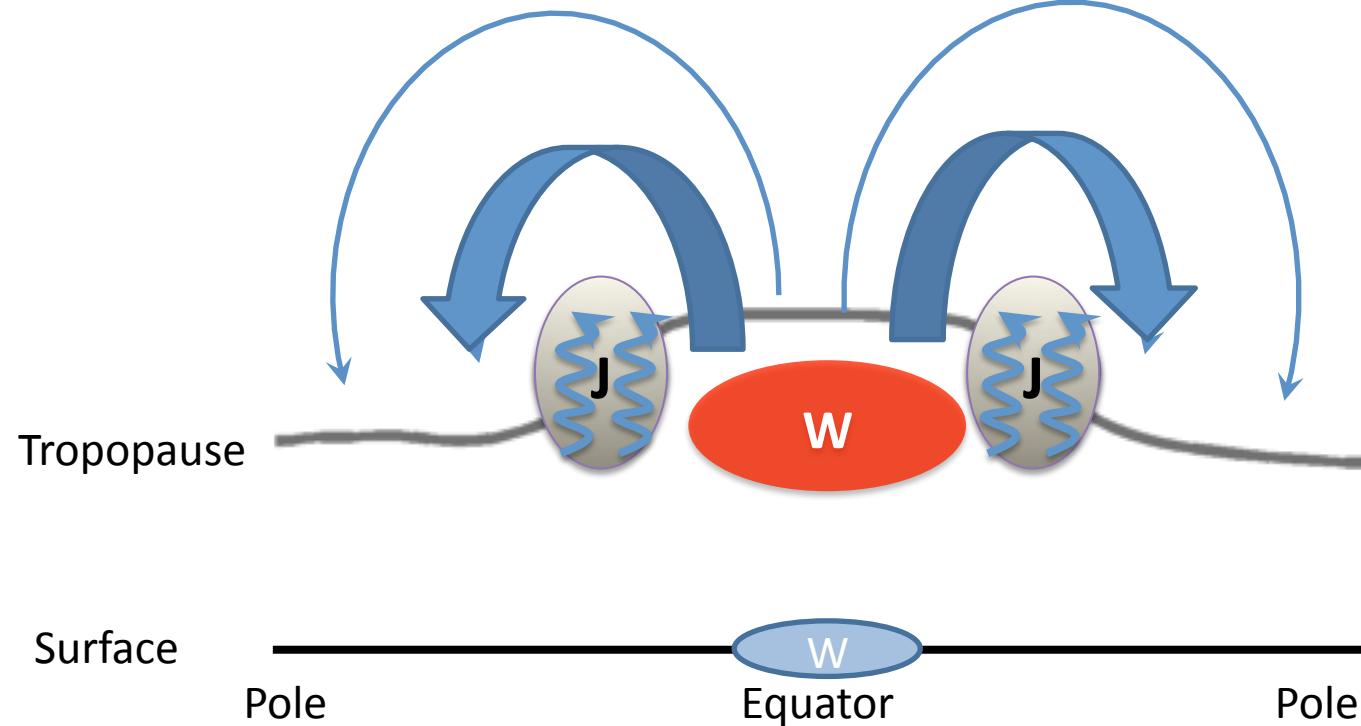
Shallow
Branch

Deep
Branch



AM3 captures
correlation of
shallow BDC
with tropical
surface
temperatures

Mechanism: critical layer control

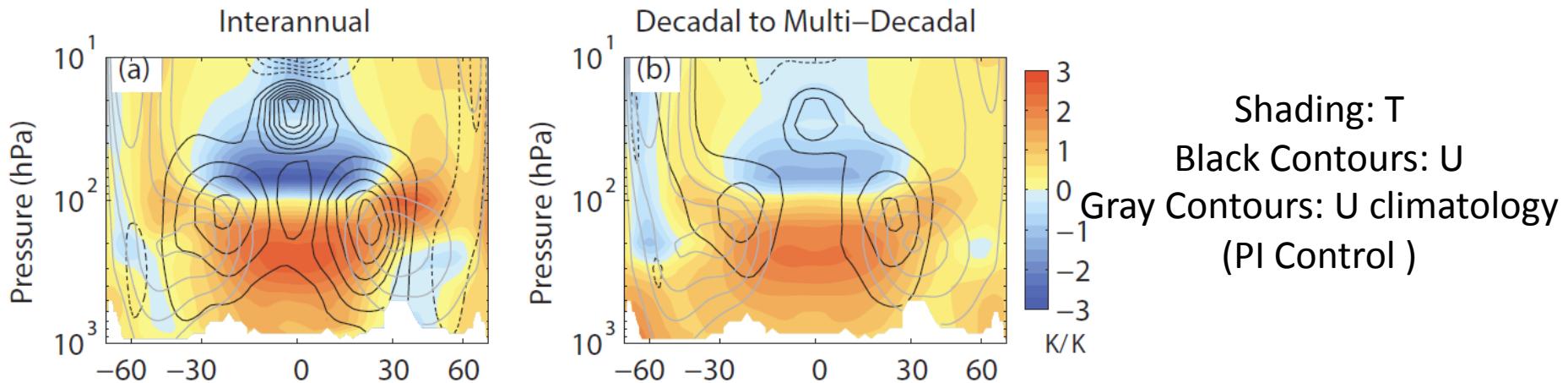


Stronger subtropical jet leads to more wave dissipation in lower stratosphere and stronger shallow branch of BDC.

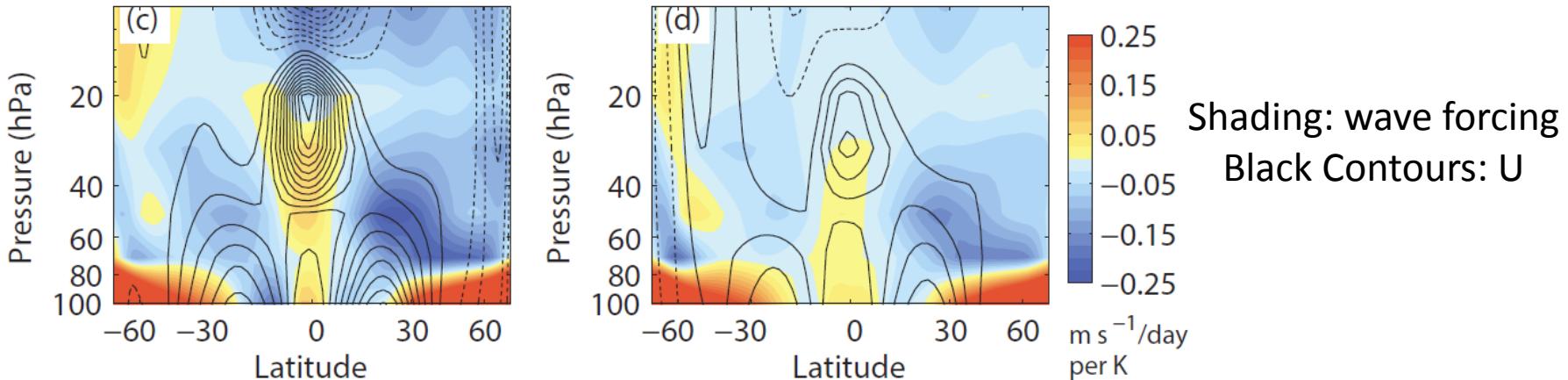
(Garcia and Randel, 2008, Shepherd and McLandress, 2011)

Response to surface warming

Regression of T and U upon tropical surface T

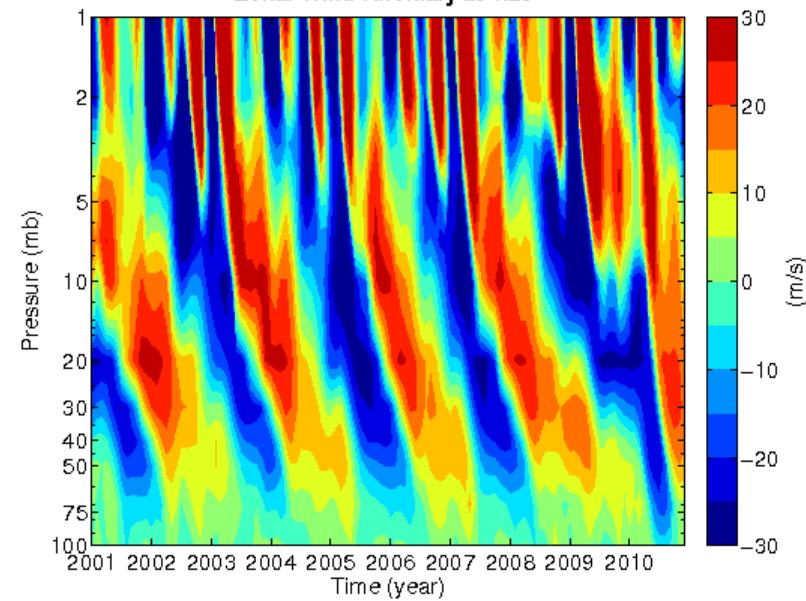


Regression of wave forcing and U upon tropical surface T



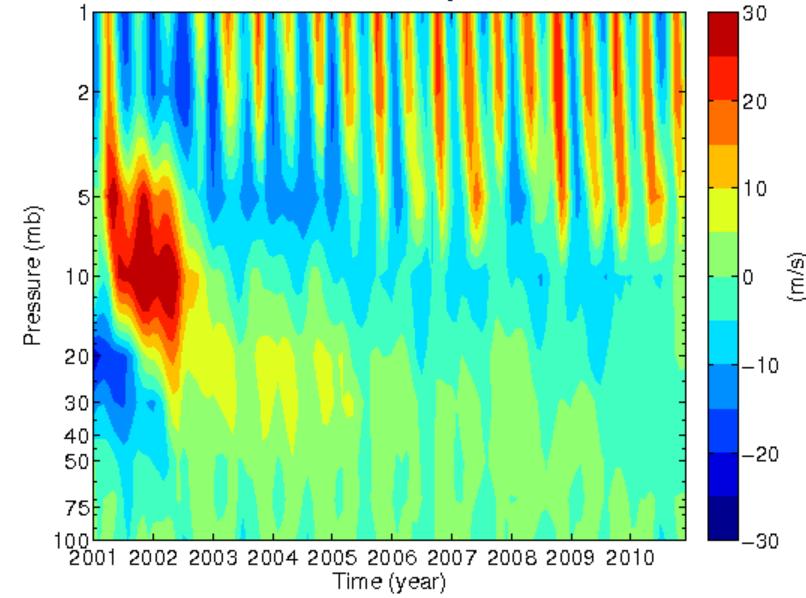
NASA Merra Data (analysis)

Zonal Wind Anomaly at 1.25°



Hydrostatic C360 HiRAM

Zonal Wind Anomaly at 1.25°



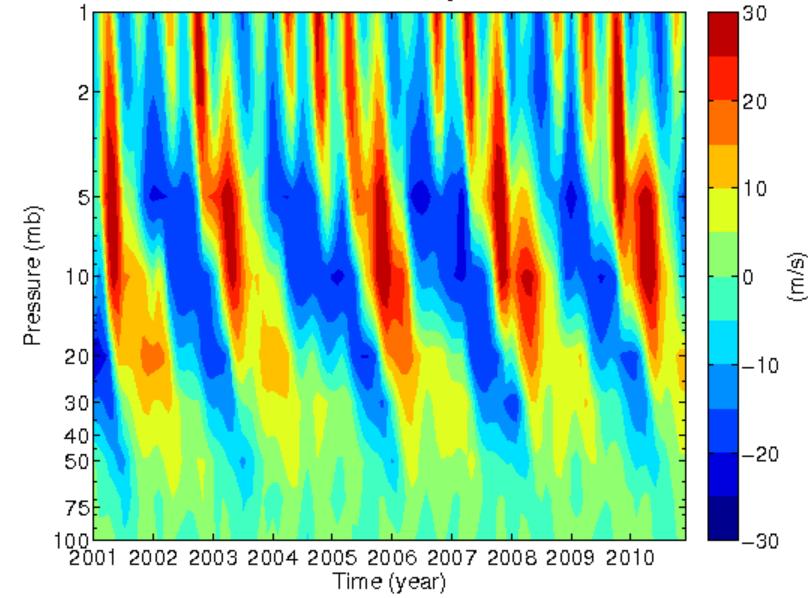
Dramatic impact of non-hydrostatic dynamics

- QBO is difficult to simulate in free-running GCMs (with or without convective GWD)
- QBO impacts sudden warmings, stratospheric ozone, and (possibly) hurricanes & winter storms

S.-J. Lin and Lucas Harris

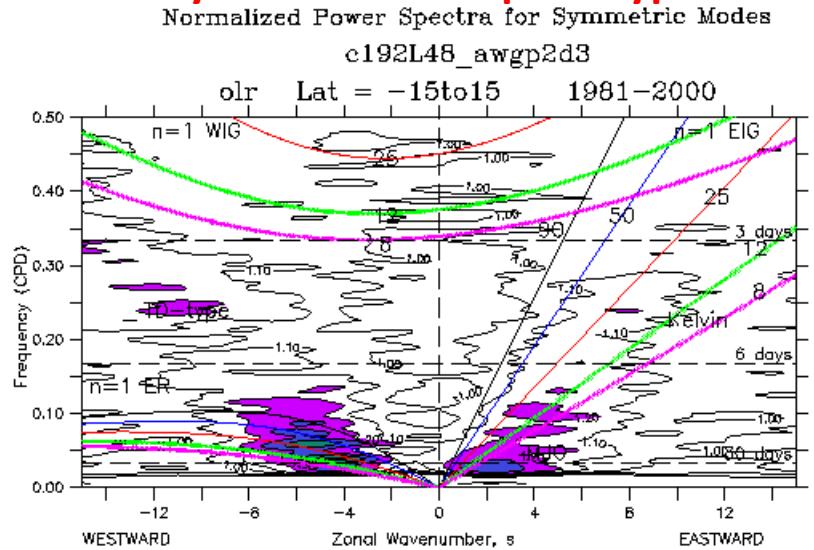
Non-hydrostatic C360 HiRAM

Zonal Wind Anomaly at 1.25°

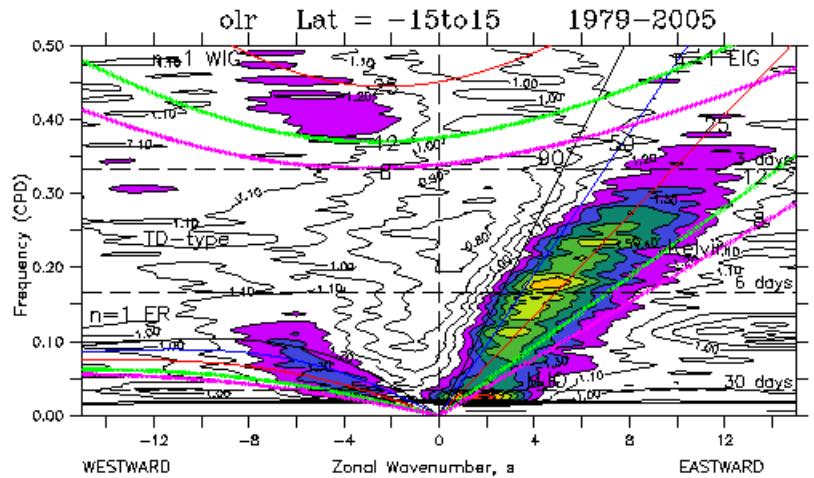


- Kelvin waves are better simulated with non-hydrostatic dynamics (all else equal)
- No QBOs if the Kelvin waves are too weak

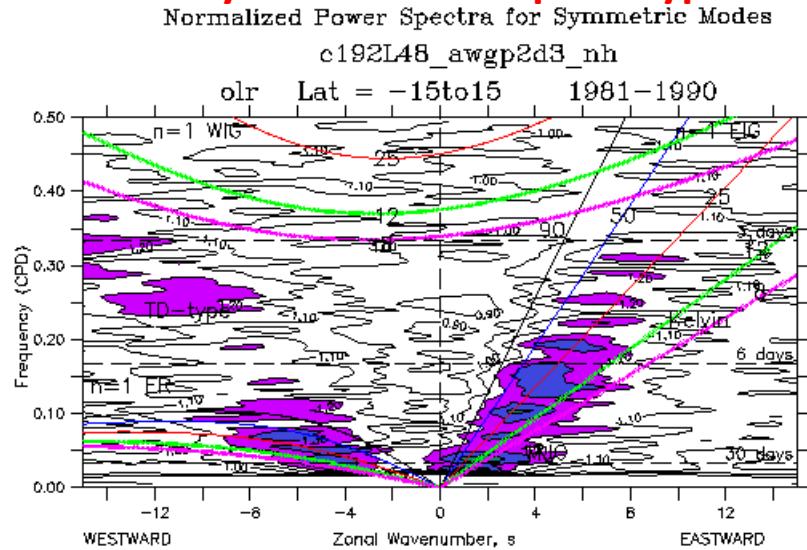
Hydrostatic AM4 prototype



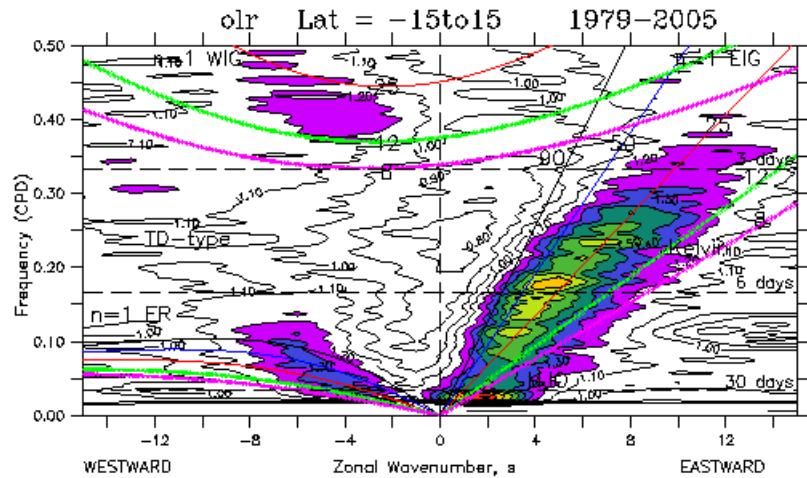
Normalized Power Spectra for Symmetric Modes NOAA_Observed_OLR



Non-hydrostatic AM4 prototype



Normalized Power Spectra for Symmetric Modes NOAA_Observed_OLR



Conclusions

- AM3/CM3 chemistry-climate model successfully simulates major features of stratospheric climate, ozone, and trends
- Response of ozone to volcanic eruptions highly sensitive to stratospheric chemical regime (halogens)
- Deep stratospheric intrusions can episodically elevate surface ozone (particularly in La Niña years over WUS)
- Tropical surface temperatures drive strength of lower branch of BDC, through modulation of wave forcing
- New non-hydrostatic cubed sphere dynamical core allows greatly improved simulation of QBO